ORIGINAL PAPER

Physiotherapy Quarterly (ISSN 2544-4395)
2024, 32(2), 62–67

Correlation of muscular strength and balance in relation to single leg squat analysis in male football players – an observational study

DOI: https://doi.org/10.5114/pq/162174

Mrugnayani Chandrashekhar Patil, Sarath Babu
MGM Institute of Physiotherapy, Aurangabad, India

Abstract

Introduction. Individual participation in sports with inadequate preparation, especially during competition, results in an increased incidence of injury. Athletes commonly suffer from lower extremity musculoskeletal pain. During growth, several biomechanical factors contribute to muscular imbalance, which results in injury. The aim of the current study was to determine the correlation between lower extremity strength and balance in relation to single leg squat depth.

Methods. A total of 100 male football players were included in the study. Lower extremity qualitative and quantitative squat analyses were performed for both legs. Isometric strength and balance for the lower extremities were assessed via a dynamometer and the Y balance test, respectively.

Results. There is a moderate correlation between the visual squat performance and the strength of the hip extensor in the dominant leg and the hip abductors in the non-dominant leg. A moderate correlation of the maximum squat depth was found with the hip abductors, hip extensor, and knee flexor on the dominant side. The *p* value was < 0.05 and the r value was between 0.50 and 0.70, which was considered significant.

Conclusions. Strength and balance both influence squat performance. Balance has a stronger influence than strength in single leg squat performance.

Key words: dominant leg, non-dominant leg, single leg squat

Introduction

Sport is a form of athletic activity involving various degrees and different levels of competition, resulting in increased competition. These competitions and the physical activity involved ultimately increase the number of injuries in young individuals [1]. Inadequate preparation during competition causes an increased incidence of injuries, suggesting that the rate of injuries is positively correlated with strength and asymmetry. As the demand exceeds capacity, excessive stress is placed on the bones, muscles and ligaments [2]. Immature athletes are more prone to injuries; evidence suggests reduced strength is an essential predictor of injury [3]. Among all injuries, lower extremity injury is more common, involving sprinting, cutting movement, weight training, or overuse. Reduced balance ability is also significantly associated with a modifiable risk factor for ankle injuries [4].

Footballers are professional athletes for whom practice requires a persistent preference for the dominant leg. During training or competition, the tremendous generation of power required to repeatedly kick the ball would develop significant asymmetry in strength, balance, and range of motion [4]. Any alteration in normal biomechanics alters the recruitment pattern of the kinetic chain as compensation. Hart et al. [5] investigated frontal plane ankle restriction, knee valgus in the frontal plane excursion, and increased peak vector GRF. These malalignments can cause muscular imbalance and associated with overuse injuries, as excessive stress is placed on the musculoskeletal structure. The single leg squat test is known to have strong potential as a functional test, as the athletic activity in football involves a component of these (isometric strength, stability and balance), movements commonly performed to return to play or progress to advanced rehabilitation [4]. At the same time, observation of movement qualities is used for sports assessment and naturally to recognise risk factors for injuries. This test is frequently performed to decide whether the athlete can return to play. Previous studies compared bone density and kinematic analysis, but very few studies have focused on correlating power with the asymmetry of the dominant and non-dominant side [4, 5]. Kim et al. [4] evaluated the relation of the single leg squat depth to the strength and range of motion of the hip, knee and ankle leg squat. This study concluded that the single leg performance can be affected by the strength of the hip flexor and ankle dorsiflexor and the range of motion of the hip, knee and ankle [4]. Mauntel et al. [6] found that the single leg squat can be affected by the gluteus medius, gluteus maximus, hip adductors, quadriceps, hamstring and medial gastrocnemius muscles as well. According to Carroll et al. [7], the single leg squat test is a functional performance test that is used by clinicians and researchers to assess the neuromuscular performance of the trunk and lower extremity. As previous studies report conflicting results on the relationship between strength, power, and dynamic balance in male football players [4, 6], the current study aims to investigate the factors causing limitations for single leg squats for the dominant and non-dominant sides.

Subjects and methods

Methodology

A total of 100 healthy football players were selected for the study after ethical clearance was obtained from the insti-

Correspondence address: Mrugnayani Chandrashekhar Patil, MGM Institute of Physiotherapy, MGM Campus, N-6 Cidco, Aurangabad 431003, India, e-mail: mrugnayanipatil19@gmail.com; https://orcid.org/0000-0002-6052-4901

Received: 30.07.2022
Accepted: 13.03.2023

Citation: Patil MC, Babu S. Correlation of muscular strength and balance in relation to single leg squat analysis in male football players – an observational study Physiother Quart. 2024;32(2):62–67; doi: https://doi.org/10.5114/pq/162174.

tutional ethical committee in line with the Declaration of Helsinki by institutional ethical committee (MGM-ECRHS/2020/08), CTRI approval (CTRI/2021/09/036494). Informed consent has been obtained from all individuals included in this study. The sample size was calculated from a previous study conducted by Booysen et al. with a confidence interval of 0.95 and a study power of 0.8 [8]. The total study duration was 18 months. The individuals selected were aged 18–25 years, with at least 2 years of football playing experience. At least for 5 hr/week of practice. The dominant leg of each participant was determined by checking which leg the individual used to kick a ball at least twice in three trials. The true limb length was measured as the distance from the anterior superior iliac spine to the medial malleolus. The leg length was measured using a standard tape measure, with the participant lying on a couch in the supine position. Both legs were straightened to equalise the pelvis (squaring of the pelvis), and the measurement was taken from the anterior superior iliac spine to the centre of the medial malleolus of the ipsilateral leg. A surface marker was used for marking over the acromion process, greater trochanter, lateral malleolus, lateral heel, and base of the fifth metatarsal on both the right and left sides. Each participant performed a warm up for 10 min, which included mobility, stretching, and functional activities. All the participants were then asked to perform a single leg squat, isometric strength test, and Y balance test.

The single-leg squat is a reliable and valid method to test lower extremity muscle power and function [9]. Both qualitative and quantitative analyses of the single-leg squat were performed by Kinovea (IDS-0.9.4-x64.zip) and observation on both the dominant and non-dominant legs. During this procedure, video was taken in the sagittal plane for quantitative analysis, where a camera was placed in line with the knee at a 1 m distance. Squat analysis was observed in the frontal plane for qualitative analysis. Before the performance, the researcher demonstrated the proper technique. The nonstance leg was kept at 90° of knee flexion and parallel to the tested limb, with the both hands crossed across the shoulder, keeping the head and neck straight by facing forwards. The single leg squat was analysed at maximum squat depth and the hip flexion, knee flexion, ankle dorsiflexion angle, and maximum squat depth were measured with a 2D Kinovea [10]. The participant was asked to practice the squats three times, then the analysis was performed on the fourth squat. In the frontal plane, the squat position was visually graded by a 3-point qualitative scale (as good, fair, and poor technique) [10, 11].

The isometric eccentric strength was measured using a baseline hydraulic analogue push-pull dynamometer for the hip flexor, hip extensor, hip abductor, hip adductor, knee flexor, knee extensor, ankle plantar flexor, and ankle dorsiflexor on the dominant and non-dominant legs. The hydraulic push pull dynamometer has good-to-excellent reliability for lower extremity muscles, except for the foot muscles [12]. The isomeric muscle strength was measured using 'make' tests, in which the subjects were asked to increase their force applied to their maximum over a 2-second period. By increasing the force gradually, it is easier for the tester to hold the dynamometer stationary against the force built by the subject. The subjects were then asked to continue with a maximum effort for another 4.0 to 5.0 s, at which time the tester asked the subject to stop and the reading was recorded [12].

The dynamic balance was assessed using the Y balance test for both the dominant and non-dominant legs, which is an instrumented version of the Star Excursion Balance Test and demonstrates good reliability in the literature [13]. A trial was discarded and repeated if the participant:

– failed to maintain a unilateral stance on the stance platform and touched the floor outside the starting zone with the reaching foot,

– placed his toes on top of the reach indicator for support,

– did not return his reach foot to the designated starting area under control,

– failed to maintain the reaching foot in contact with the reach indicator on the red target area while it was in motion,

– lifted the stance leg heel off the platform or removed his hands from his hips.

A 15-s rest period after each trial was given as a washout period to reduce the effect of fatigue, along with 3-min rest breaks between each direction. The reach distance in each direction was measured in cm. Each direction was averaged over the three trials and normalised to the leg length. The balance performance for the anterior, posteromedial and posterolateral direction for each leg was calculated by normalising the reach score in all directions with the limb length [13]:

$$\text{Balance in anterior (direction)} = \text{reach distance anterior} / \text{limb length} \cdot 100$$

The same investigator tested all the outcome measures.

The Pearson correlation coefficient was calculated to determine any correlation between strength and balance with the single-leg squat analysis. Data was entered into Microsoft Excel and analysed using the SPSS version 24.0 software. Table 1 shows anthropometric measurements and demographic data and Table 2 shows the mean and SD of the single leg squat, strength, and balance. Tables 3 and 4 show the correlation coefficient and p-value for the dominant and non-dominant sides, respectively, for the squat analysis with the strength and balance parameters. A correlation of the r value, for p-value < 0.05, was noted as a significant correlation.

Results

In the current study, the results show a moderate correlation between the visual squat score on the strength of the hip extensor in the dominant leg and the hip abductors in the non-dominant leg. The Kinovea analysis shows a moderate correlation between the maximum squat depth and the hip abductors, hip extensor, and knee flexor on the dominant side. Balance in the anterior and posterolateral direction affects squat performance on both the dominant and non-dominant sides.

We found that the maximum squat depth was negatively correlated with the strength of the hip and knee extensors with balance in the anterior and posterolateral directions. The hip flexion angle during a maximum squat positively correlated with the hip extensor strength. Similarly, the hip flexion angle was positively correlated with balance on the anterior and posterolateral sides of the squatting leg. A positive correlation was also found between the hip flexor strength and anterior and posterolateral balance. The knee flexion angle during a maximum squat was moderately positively correlated with balance in all directions. Similarly, the knee flexion angle was weakly correlated with the strength of the hip flexor and abductor on the squatting side. On the contralateral side to squatting, there exists a positive correlation with the strength of the hip and knee muscles and balance in the posterolateral direction. The ankle flexion angle had a weak positive correlation with the strength of the hip and knee flexor on the ipsilateral side. The ankle flexion angle was weakly positively correlated with the strength of the knee flexor on the contralateral side. The visual squat score weakly positively cor-

Table 1. Demographic and anthropometric parameters of subjects

Characteristic	Subjects (n = 100) mean ± *SD*
Age (years)	20.02 ± 2.2
Body height (cm)	173.56 ± 10.4
Body mass (kg)	65.53 ± 7.27
Body mass index (kg/m^2)	21.90 ± 3.06
Leg length (cm)	82.45 ± 12.77
Training experience (years)	2.55 ± 1.10

Table 2. Mean and *SD* for single leg squat, strength and balance

Outcomes	Parameters	Dominance	Mean ± *SD*
Squat analysis	visual squat score	D	1.47 ± 0.64
		ND	2.37 ± 1.91
	hip angle	D	116.2 ± 31.8
		ND	121.05 ± 28.37
	knee angle	D	90.95 ± 33.9
		ND	90.17 ± 21.9
	ankle angle	D	58.20 ± 6.10
		ND	53.97 ± 7.27
	maximum squat depth	D	41.62 ± 14.11
		ND	45.58 ± 13.54
Strength	hip flexor	D	25 ± 6.5
		ND	22.12 ± 6.2
	extensor	D	28.3 ± 6.6
		ND	25.25 ± 5.94
	abductors	D	27.77 ± 7.35
		ND	29.25 ± 5.23
	adductors	D	26.29 ± 9.46
		ND	22.8 ± 9.3
	knee flexor	D	22.87 ± 4.33
		ND	20.63 ± 4.01
	knee extensor	D	24.97 ± 7.09
		ND	21.13 ± 6.9
	ankle plantarflexor	D	9.03 ± 1.3
		ND	18.49± 1.89
	ankle dorsiflexion	D	9.4 ± 1.1
		ND	9.6 ± 1.1
Balance	anterior	D	69.09 ± 7.85
		ND	70.95 ± 10.45
	posteromedial	D	64.78 ± 8.62
		ND	64.52 ± 8.62
	posterolateral	D	68.24 ± 9.72
		ND	66.57 ± 10.42

D – dominant, ND – non-dominant

related with the strength of the hip adductor, hip abductor, and knee flexor. Similarly, the visual squat score was found to have a moderate correlation with balance on the posterolateral and posteromedial sides of the squatting leg. The visual squat score was found to have a weak positive correlation with the contralateral hip flexor and extensor, knee flexor and extensor and balance in the posterolateral directions.

Discussion

The present study aims to study the correlation between the lower extremity strength and balance with the single-leg squat depth. The results show a moderate correlation between the visual squat performance and the strength of the hip extensor in the dominant leg and the hip abductors in the non-dominant leg. A moderate correlation between the maximum squat depth with the hip abductor, hip extensor, and knee flexor on the dominant side was also found. Balance in the anterior and posterolateral directions affects squat performance on both the dominant and non-dominant sides.

Correlation of hip, knee, and ankle muscle strength with squat analysis

It was found that the visual squat score was moderately correlated with the hip extensor strength and weakly correlated with the knee flexor and extensor strength for the dominant leg. The visual squat score was moderately correlated with the hip abductor and weakly correlated with the hip flexor and extensors of the non-dominant leg.

In Plisky et al. [13], segmental criteria were used to predict lower-body and lower extremity injury. This study established that the single leg squat shows 68% knee valgus stress and demonstrated weakness in the hip abductor, knee flexor, and knee extensor peak torque [13]. Weeks et al. found that knee mediolateral displacement significantly predicted single-leg squat performance, so preventive exercise programs should include the screening of movement to identify limitations in hip abductor, hamstring, and quadriceps and technique correction to avoid injuries [14]. A moderate correlation was found for the hip abductor, external rotator, and extensor strength in a single leg squat at 60° of knee flexion [15, 16]. Muscle recruitment pattern changes in the dominant and non-dominant legs in individuals playing unilateral dominant sports. Svensson et al. [17] found that the hamstring muscle has less strength in the dominant leg when compared to the non-dominant leg due to its constant use for power generation through the knee extensors, resulting in a greater disproportion between the quadriceps and hamstring. These asymmetrical muscle strengths cause differences in movement while performing a squat assessment [18]. In contrast, Dix et al. revealed in a meta-analysis that lower extremity valgus was consistently associated with hip strength in single-leg ballistic tasks, but not in the single-leg squat and double-leg ballistic tasks. In this study, they concluded that the relationship between the leg was conditioned by the task [19].

Correlation of balance with squat analysis

A moderate negative correlation between the maximum squat depth and balance in all three directions on both the dominant and non-dominant sides was found. The squat depth increases as the distance from the ground to the greater trochanter decreases, so the smaller the distance, the better the balance. Scudamore et al. [20], found that the composite reach and overall stability indices are two dynamic balance

Table 3. Dominant side squat analysis

Kinovea measure		Hip flexor	Hip add	Hip abd	Hip ext	Knee flexor	Knee ext	Ankle pla	Ankle dor	B ant	B post M	B post L
VSS	*r*	0.101	0.1853	0.0766	0.4035	0.2542	0.304	0.0009	–0.259	0.413306	0.324086	0.36396
	p	0.289	0.0327	0.2635	**0.0002**	**0.0002**	**0.0019**	0.3258	0.4099	**0.0001**	0.0055	**0.0003**
Hip A	*r*	0.067	0.0419	–0.157	0.2829	0.2271	0.2291	0.0063	–0.056	0.246233	0.198949	0.342635
	p	0.26	0.2476	0.1114	**0.003**	**0.0114**	**0.0075**	0.3428	0.7081	**0.02635**	0.067	**0.0012**
Knee A	*r*	–0.046	–0.014	–0.157	–0.055	–0.082	0.117	0.0575	–0.104	0.537036	0.345994	0.567664
	p	0.384	0.496	0.0736	0.235	0.0942	0.076	0.3106	0.056	**0.0001**	**0.00019**	**0.0001**
Ankle A	*r*	0.33	0.0349	0.0492	–0.139	–0.046	–0.082	0.278	–0.127	–0.08252	0.236459	–0.13509
	p	**5E–04**	0.1866	0.2179	0.3537	0.3573	0.4642	0.1232	0.1143	0.0634	0.0757	**0.0239**
MSD	*r*	0.558	0.5874	0.7348	0.6028	0.6372	0.6021	0.7189	0.7928	0.664558	0.653615	–0.52804
	p	**0.006**	0.276	**0.0167**	**0.0008**	**0.0001**	0.4127	0.2908	0.2517	**0.0001**	**0.0001**	**0.0001**

Hip add – hip adductor, Hip abd – hip abductor, Hip ext – hip extensor, Ankle pla – ankle plantarflexor, Ankle dor – ankle dorsiflexor,
B ant – anterior balance, B post M – posteromedial balance, B post L – posterolateral balance
VSS – visual squat score, Hip A – hip angle, Knee A – knee angle, Ankle A – ankle angle, MSD – maximum squat depth
bold – significant correlation

Table 4. Non-dominant side squat analysis

Kinovea measure		Hip flexor	Hip add	Hip abd	Hip ext	Knee flexor	Knee ext	Ankle pla	Ankle dor	B Ant	B Post M	B Post L
VSS	*r*	0.345	0.2555	0.431	0.3439	0.1419	0.279	0.0557	–0.06	0.482676	0.151549	0.475995
	p	**2E–04**	**0.0057**	**0.0001**	**0.0002**	0.0797	**0.0025**	0.2213	0.5525	**0.0001**	0.1324	**0.0001**
Hip A	*r*	–0.038	0.0883	0.1408	0.0291	–0.04	0.12	0.1311	0.0645	0.366731	0.100014	0.321439
	p	0.346	0.1912	0.0809	0.383	0.346	0.1172	0.1751	0.5269	**0.0001**	0.3222	**0.0011**
Knee A	*r*	–0.054	–0.022	0.206	–0.061	–0.233	0.0379	0.1235	0.06	0.37225	0.164402	0.249218
	p	0.311	0.414	**0.0199**	0.276	**0.009**	0.3542	0.2963	0.5538	**0.0001**	0.1021	**0.0001**
Ankle A	*r*	–0.106	–0.304	–0.079	–0.067	0.3792	0.1568	–0.071	0.1001	0.132132	–0.2353	–0.06577
	p	0.293	**0.0011**	0.2173	0.244	**0.0001**	0.0597	**0.0126**	0.3217	0.1901	0.0184	0.5166
MSD	*r*	0.438	0.3166	0.597	0.5195	0.6363	0.56	0.7668	0.7692	0.761358	0.662843	–0.39522
	p	**1E–04**	**0.0004**	**0.0002**	**0.0001**	**0.0027**	0.5	0.2526	0.0842	0.1884	**0.00042**	0.00015

Hip add – hip adductor, Hip abd – hip abductor, Hip ext – hip extensor, Ankle pla – ankle plantarflexor, Ankle dor – ankle dorsiflexor,
B ant – anterior balance, B post M – posteromedial balance, B post L – posterolateral balance
VSS – visual squat score, Hip A – hip angle, Knee A – knee angle, Ankle A – ankle angle, MSD – maximum squat depth
bold – significant correlation, E – exponential power (2E = 10^{2})

assessment tools helpful for predicting functional movement score items in young, active men and women.

Similar results were found in a study on military recruits, which included a total of 135 males, prospectively followed for 6 weeks to find the incidence of PFPS [21]. They investigated dynamic balance and the frontal plane knee proprioception angle. They concluded that greater asymmetry on the Y balance test in the posterolateral direction (> 4.08 cm) is one of the causes of patellofemoral pain syndrome. A strong positive correlation existed between posteromedial reach with externally applied flexor moment ($r = 0.56$, $p < 0.001$), and a moderate negative correlation existed between anterior reach and internal rotation moment. When we consider factors affecting the single-leg squat, a large relationship was observed between balance and moderate strength. Poor balance performance was associated with a poorer overall squat impression, especially in a visual squat analysis [21]. A significant moderate relationship was observed between power and balance for both legs. A study by Erkmen et al. [16] made a similar finding: a moderate inverse correlation ($r = –0.59$, $p < 0.05$) with single leg balance error on the non-dominant leg and countermovement jump height. They concluded that footballers jumped higher and also made fewer balance errors [15]. Future studies should focus on evaluating other factors in addition to strength and balance, including joint proprioception, motor control, range of motion, and muscle recruitment pattern, which could affect squat performance. Isokinetic strength testing is a better predictor of symmetry than isometric strength.

Limitations

The current study has limitations, as push-pull dynamometers have poor reliability for ankle muscles and the visual squat analysis used 3-point grading, which assesses only 3 deviations from the normal squat.

Conclusions

There was a moderate correlation between the visual squat performance on the strength of the hip extensor in the dominant leg and the hip abductors in the non-dominant leg. A moderate correlation was found between the maximum squat depth and the hip abductors, hip extensor, and knee flexor on the dominant side. Balance in the anterior and posterolateral directions affects squat performance on both the dominant and non-dominant sides.

Clinical implications

Training strategies should focus on the strength of the hip abductors, hip extensors, and knee flexors to improve the quality of squatting. During single-leg squats, balance had a stronger influence than strength, so focusing on the balance component can enhance the squat performance. Squat depth can be improved by improving the strength of the hip abductors, extensors, and knee flexors. Similarly, the squat depth can be improved by improving the balance in the anterior and posteromedial directions. The risk of injury can be reduced by focusing on these parameters having a moderate correlation with the squat analysis.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the institutional ethical committee (approval No.: MGM-ECRHS/2020/08).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Funding

This research received no external funding.

References

[1] Cai W, Gao Y, Yang W, Cheng F, Tang D, Li L. Physical activity-related injury and its associated factors among middle school students in Southern China. Int J Environ Res Public Health. 2018;15(6):1244; doi: 10.3390/ijerph15061244.

[2] Chambers RB. Orthopedic injuries in athletes (ages 6 to 17): comparison of injuries occurring in six sports. Am J Sports Med. 1979;7(3):195–7; doi: 10.1177/036354657900700312.

[3] Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for acute ankle injuries among male soccer players: a prospective cohort study: risk factors for ankle injuries in soccer. Scand J Med Sci Sports. 2009;20(3):403–10; doi: 10.1111/j.1600-0838.2009.00971.x.

[4] Kim S-H, Kwon O-Y, Park K-N, Jeon I-C, Weon J-H. Lower extremity strength and the range of motion in relation to squat depth. J Hum Kinet. 2015;45(1):59–69.

[5] Hart NH, Nimphius S, Weber J, Spiteri T, Rantalainen T, Dobbin M, Newton RU. Musculoskeletal asymmetry in football athletes: a product of limb function over time. Med Sci Sports Exerc. 2016;48(7):1379–87; doi: 10.1249/MSS.0000000000000897.

[6] Mauntel TC, Begalle RL, Cram TR, Frank BS, Hirth CJ, Blackburn T, Padua DA. The effects of lower extremity muscle activation and passive range of motion on single leg squat performance. J Strength Cond Res. 2013;27(7):1813–23; doi: 10.1519/JSC.0b013e318276b886.

[7] Carroll LA, Kivlan BR, Martin RL, Phelps AL, Carcia CR. The single leg squat test: a “top-down” or “bottom-up” functional performance test?. Int J Sports Phys Ther. 2021;16(2):360–70; doi: 10.26603/001c.21317.

[8] Booysen MJ, Gra didge PJ, Watson E. The relationships of eccentric strength and power with dynamic balance in male footballers. J Sports Sci. 2015;33(20):2157–65.

[9] DiMattia MA, Livengood AL, Uhl TL, Mattacola CG, Malone TR. What are the validity of the single-leg-squat test and its relationship to hip-abduction strength?. J Sport Rehabil. 2005;14(2):108–23; doi: 10.1123/jsr.14.2.108.

[10] Puig-Divi A, Escalona-Marfil C, Padullés-Riu JM, Busquets A, Padulles-Chando X, Marcos-Ruiz D. Validity and reliability of the Kinovea program in obtaining angles and distances using coordinates in 4 perspectives. PLoS One. 2019;14(6):e0216448; doi: 10.1371/journal.pone.0216448.

[11] Wilczyński B, Wąż P, Zorena K. Impact of three strengthening exercises on dynamic knee valgus and balance with poor knee control among young football players: a randomized controlled trial. Healthcare. 2021;9(5):558; doi: 10.3390/healthcare9050558.

[12] Mentiplay BF, Perraton LG, Bower KJ, Adair B, Pua YH, Williams GP, McGaw R, Clark RA. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. PLoS One. 2015;10(10):e0140822; doi: 10.1371/journal.pone.0140822.

[13] Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. N Am J Sports Phys Ther. 2009;4(2):92–9.

[14] Weeks BK, Carty CP, Horan SA. Kinematic predictors of single-leg squat performance: a comparison of experienced physiotherapists and student physiotherapists. BMC Musculoskelet Disord. 2012;13(1):1–7; doi: 10.1186/1471-2474-13-207.

[15] Erkmen N, Taskin H, Sanioglu A, Kaplan T, Basturk D. Relationships between balance and functional performance in football players. J Hum Kinet. 2010;26(1):187.

[16] O’Connor S, McCaffrey N, Whyte EF, Moran KA. Can a standardized visual assessment of squatting technique and core stability predict injury?. J Strength Cond Res. 2020;34(1):26–36; doi: 10.1519/JSC.0000000000003262.

[17] Svensson K, Eckerman M, Alricsson M, Magounakis T, Werner S. Muscle injuries of the dominant or non-dominant leg in male football players at elite level. Knee Surg Sports Traumatol Arthrosc. 2018;26(3):933–7; doi: 10.1007/s00167-016-4200-4.

[18] Stickler L, Finley M, Gulgin H. Relationship between hip and core strength and frontal plane alignment during a single leg squat. Phys Ther Sport. 2015;16(1):66–71; doi: 10.1016/j.ptsp.2014.05.002.

[19] Dix J, Marsh S, Dingenen B, Malliaras P. The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: a systematic review. Phys Ther

Sport. 2019;37:197–209; doi: 10.1016/j.ptsp.2018.05.015.
[20] Scudamore EM, Stevens SL, Fuller DK, Coons JM, Morgan DW. Use of functional movement screen scores to predict dynamic balance in physically active men and women. J Strength Cond Res. 2019;33(7):1848–54; doi: 10.1519/JSC.0000000000002829.
[21] Nakagawa TH, Dos Santos AF, Lessi GC, Petersen RS, Silva RS. Y-balance test asymmetry and frontal plane knee projection angle during single-leg squat as predictors of patellofemoral pain in male military recruits. Phys Ther Sport. 2020;44:121–7; doi: 10.1016/j.ptsp.2020.05.011.